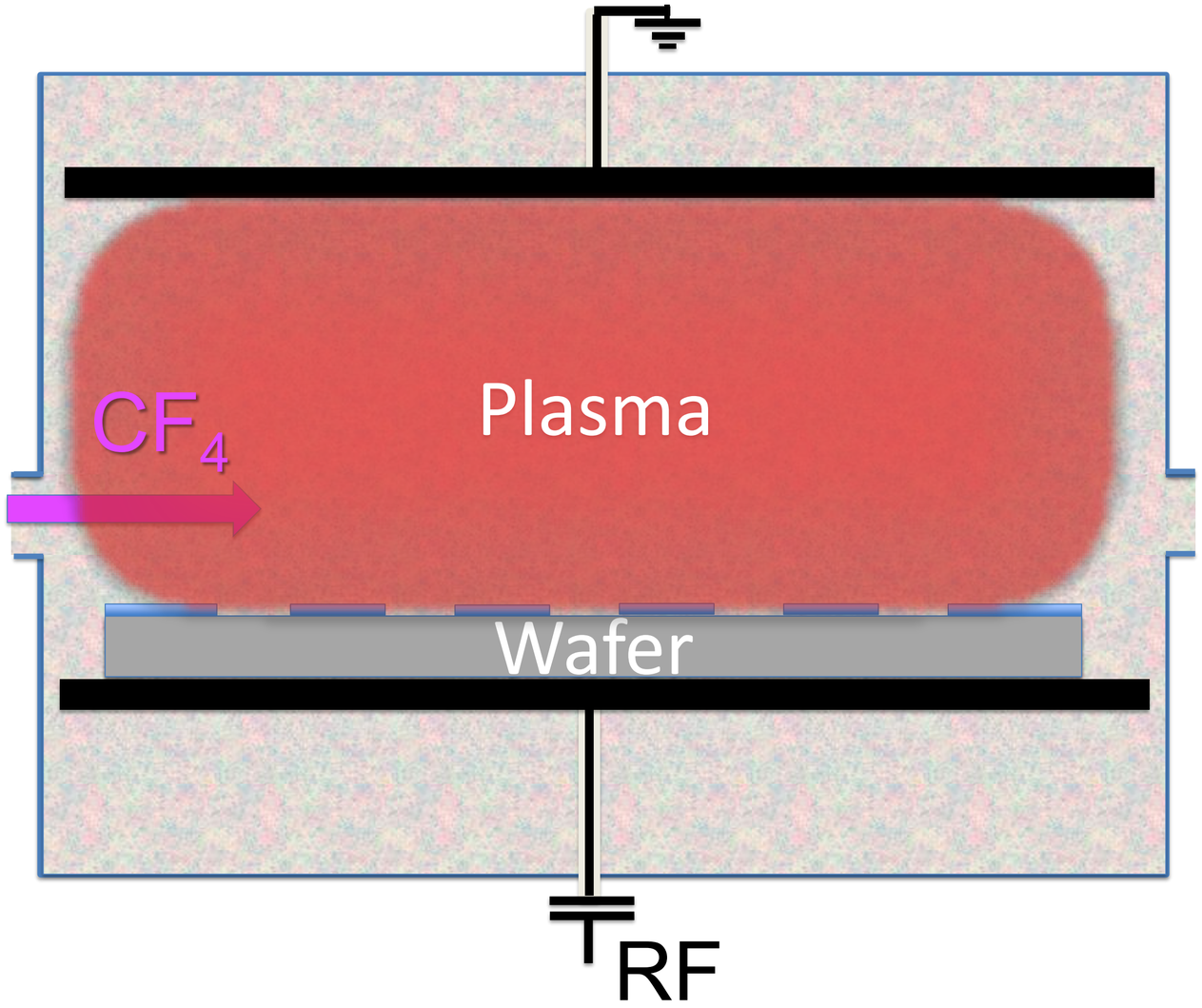
Dry etching Classroom slides

27 Nov 2024

Micro and Nanofabrication (MEMS)

Prof. hon. Martin A. M. Gijs



- Chemically reactive fluorine radicals are produced in a plasma upon impact on the CF_4 with an electron e^- from the plasma

$$CF_4 + e^- \rightarrow CF_3{}^+ + F + 2e^-$$

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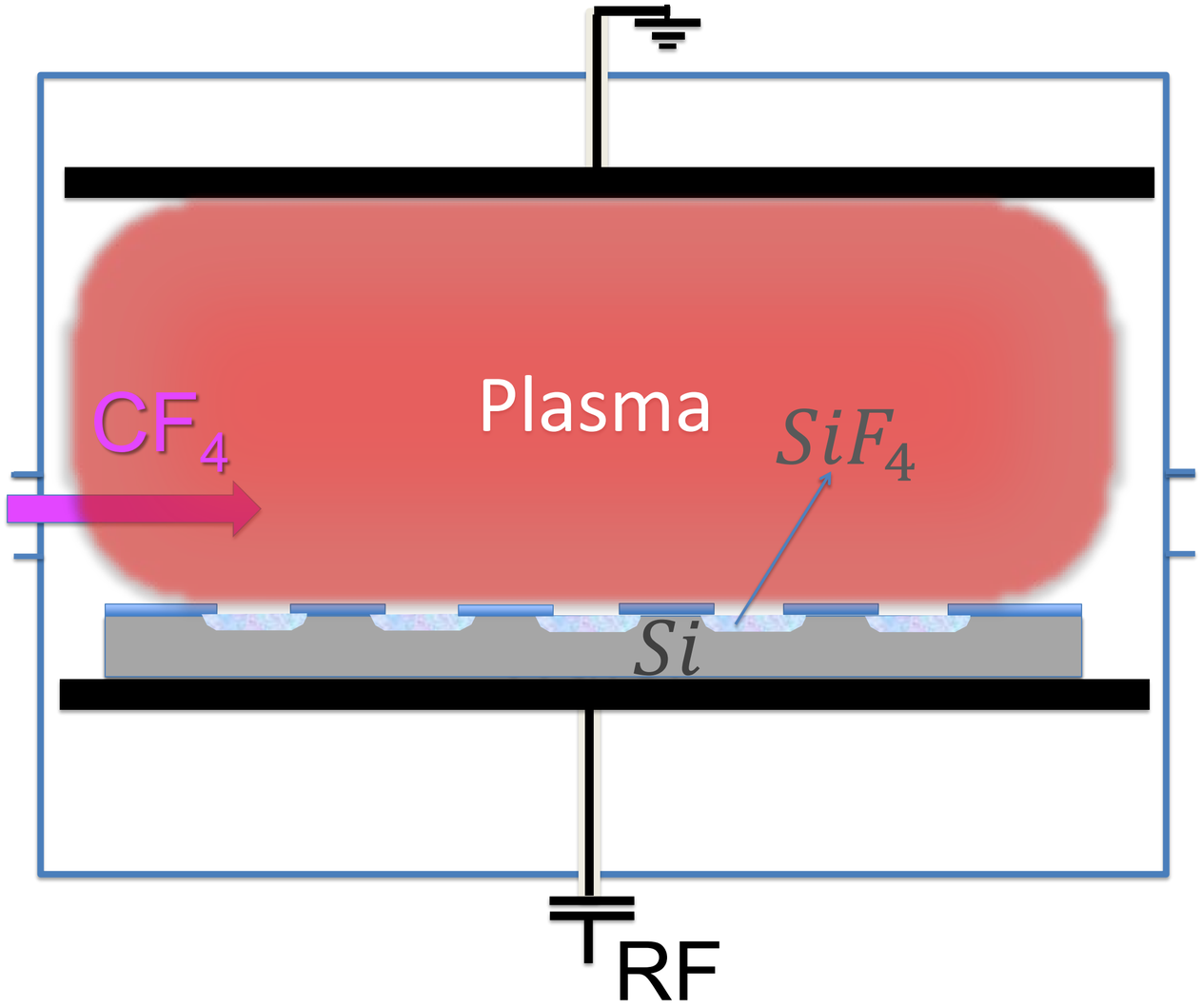

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$$CF_4 + e^- \rightarrow CF_3{}^+ + F + 2e^-$$
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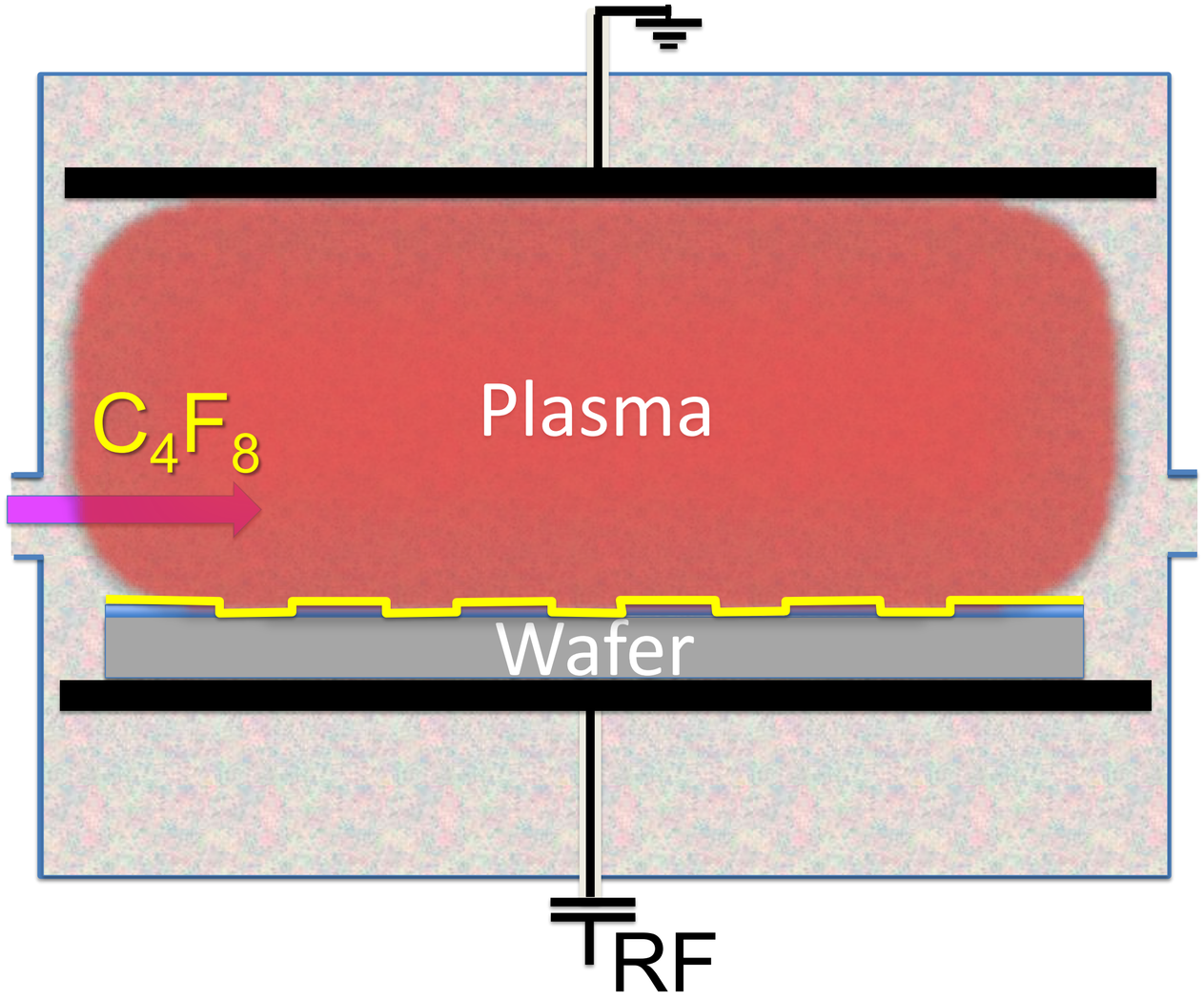
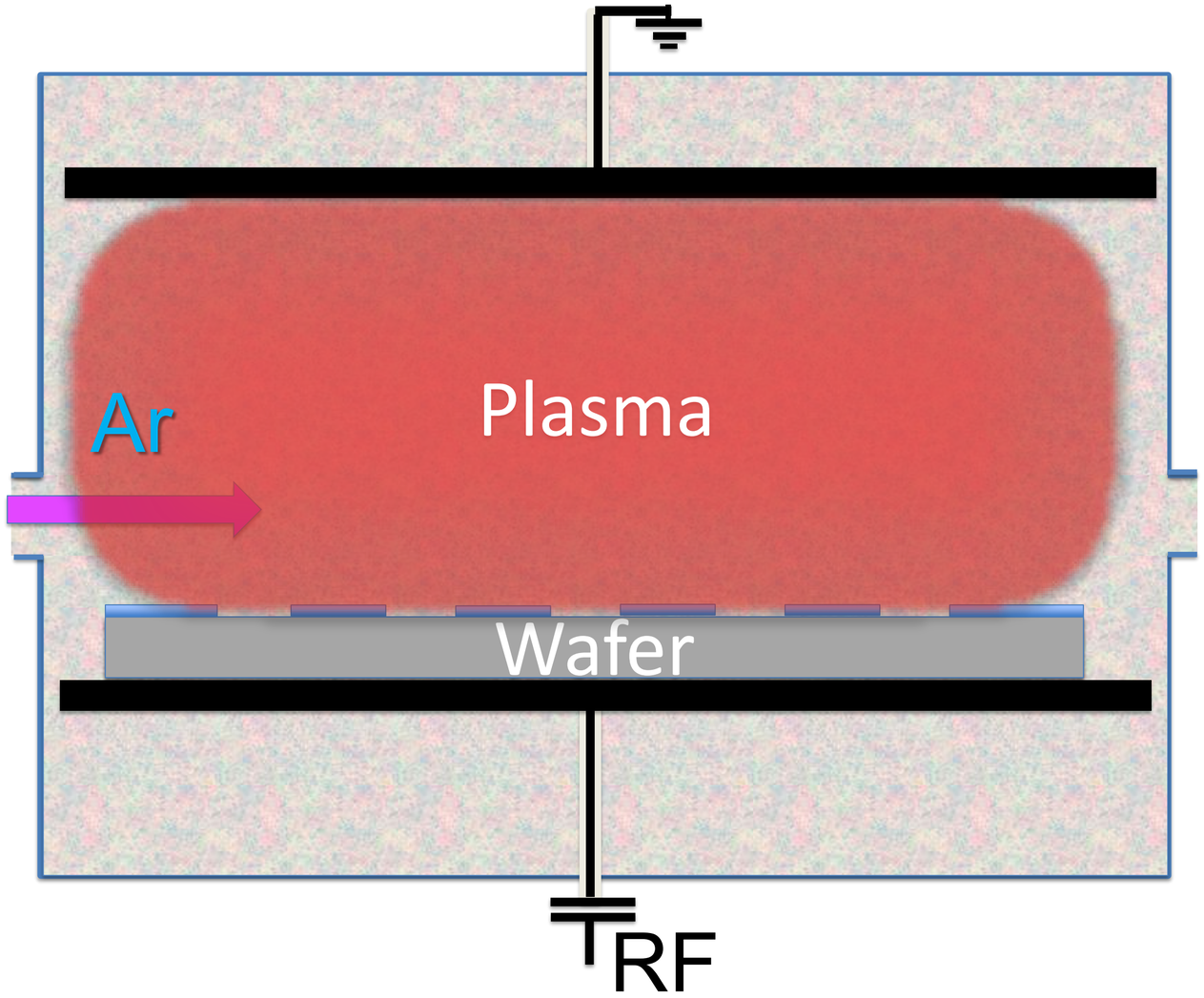
- Fluorine radicals etch the Si in an isotropic way, i.e. mask underetching occurs

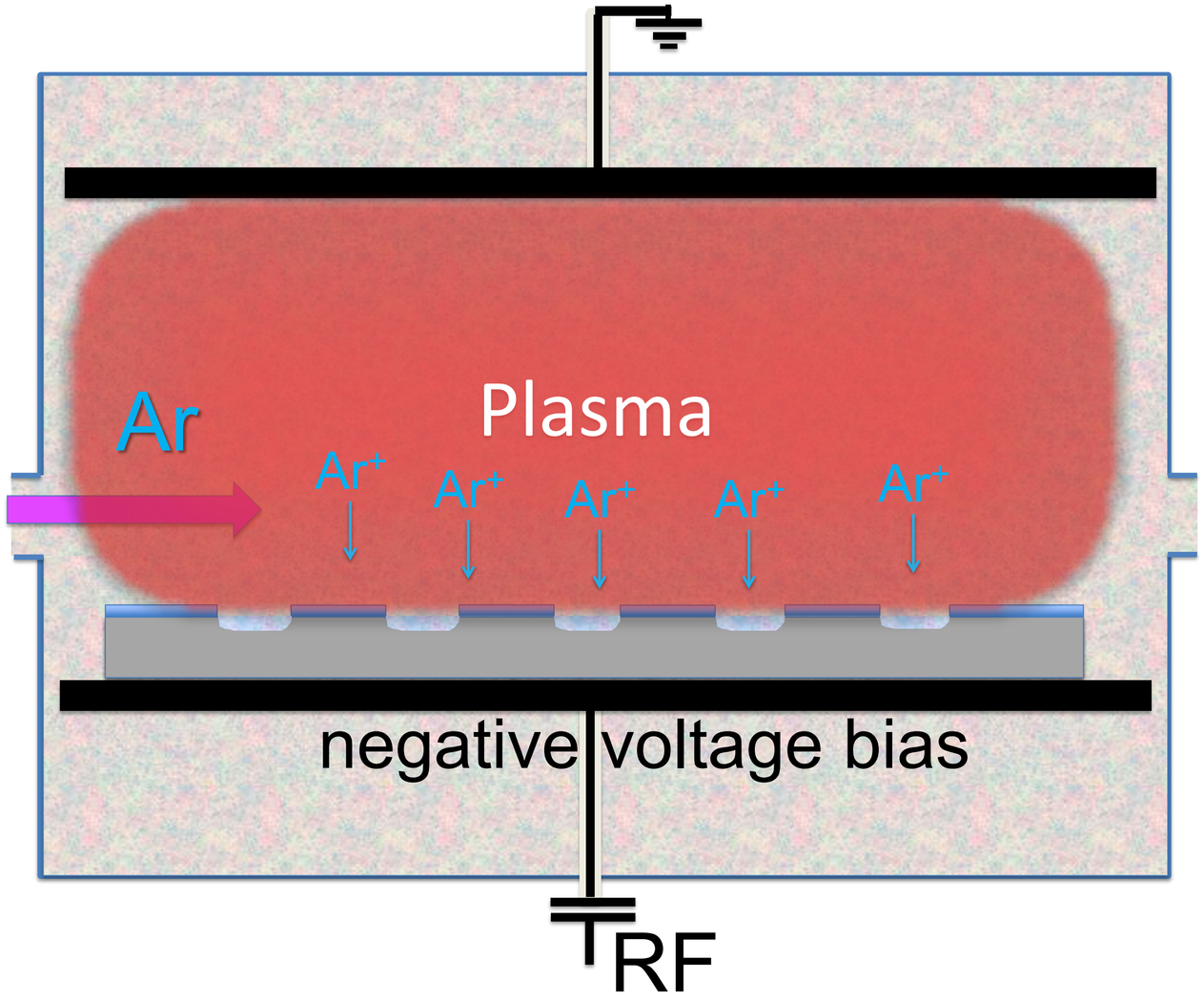
$$Si(s) + 4F(g) \rightarrow SiF_4\ (g)$$



- If a carbon-rich gas like octafluorocyclobutane (C_4F_8) is used, this can lead to deposition of $(CF_2)_n$-type polymer chains
- The result is deposition of a smooth fluorocarbon polymer passivating film, rather than etching

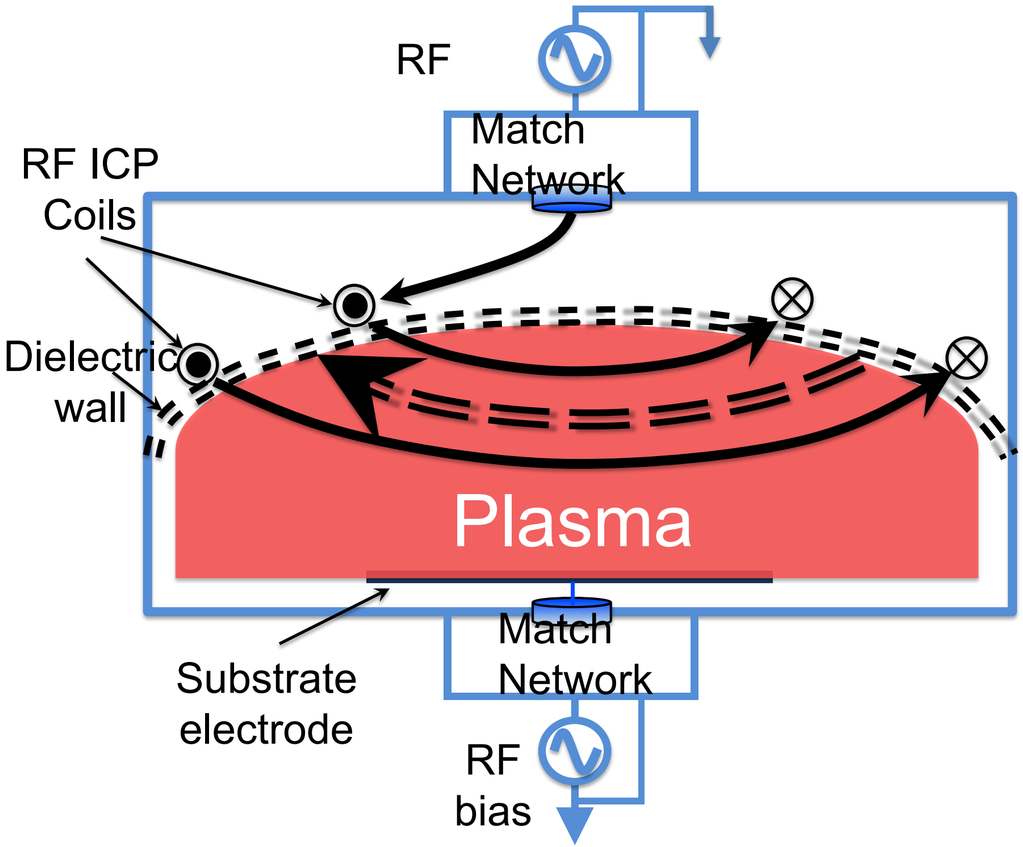


- If an inert gas like Ar is used, there is no reaction with the silicon



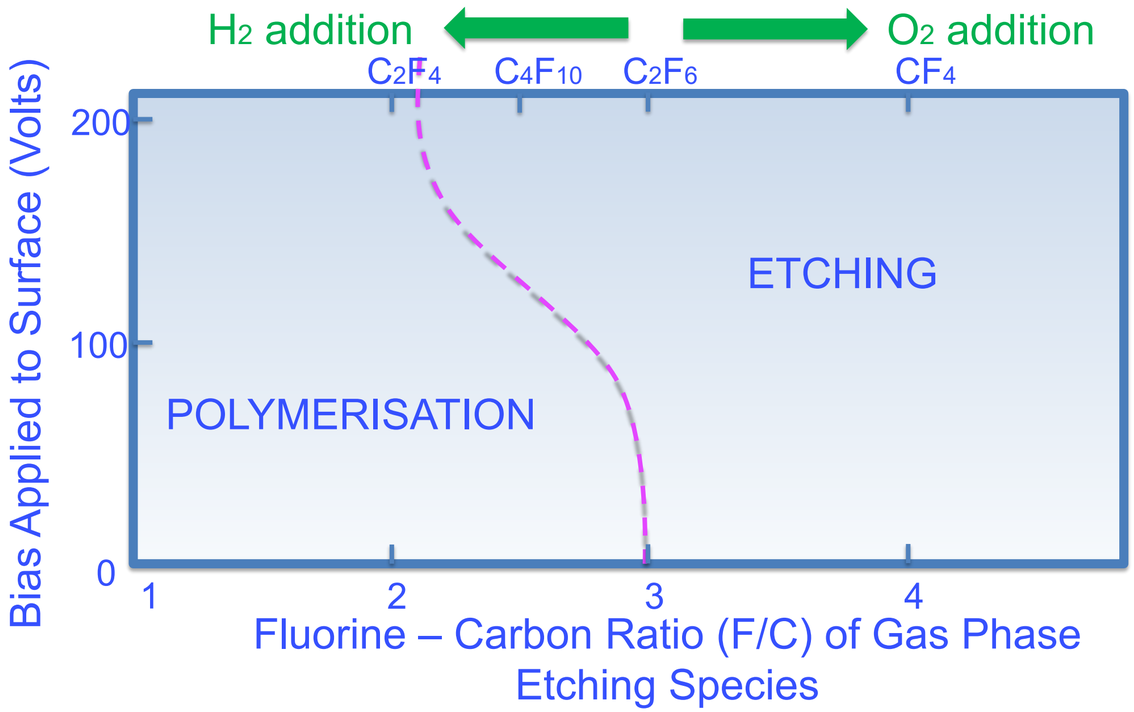
- If an inert gas like Ar is used, there is no reaction with the silicon
- However, if a negative voltage bias is applied to the wafer, Ar^+ ions are accelerated towards the wafer and remove Si by physical impact
- This leads to anisotropic etching, i.e. there is no mask underetching
- Also the mask will be exposed to the physical impact and will be consumed

Inductively coupled plasma (ICP) source



- RF coil (13.56 MHz) is separated from the plasma by a dielectric wall (planar, cylindrical or dome shape) + vacuum barrier
- An RF current in the coil induces an opposing RF current in the plasma, concentrated within a skin depth (few cm) of the plasma surface
- The plasma acts as a secondary of a transformer with the ICP coil as the primary
- The RF current is carried primarily by thermal electrons
- Rapid power transfer to the plasma by e^- neutral collisions

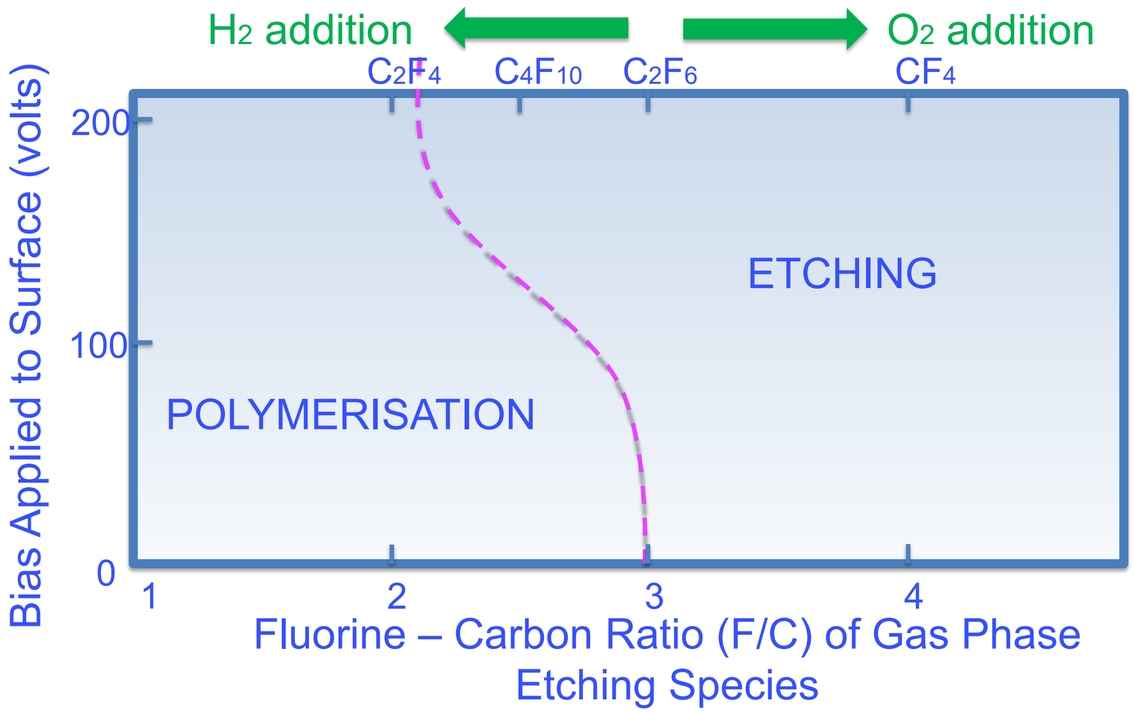
Increasing the anisotropy by sidewall protection



Boundary between etching and polymerization in fluorocarbon plasma as a function of F/C ratio (feed gas) and of the ion bombardment of the surface

- Halocarbon-based plasmas contain etchant species (F, Cl, Br) and carbon halogen radicals (CF_x, CCl_x, CBr_x, $0<x<3$) and have very low spontaneous etch rate without negative voltage substrate bias
- Polymeric thin film formation decreases for increasing F/C ratio, ion energy and flux towards the substrate (related to the substrate bias), and the substrate temperature

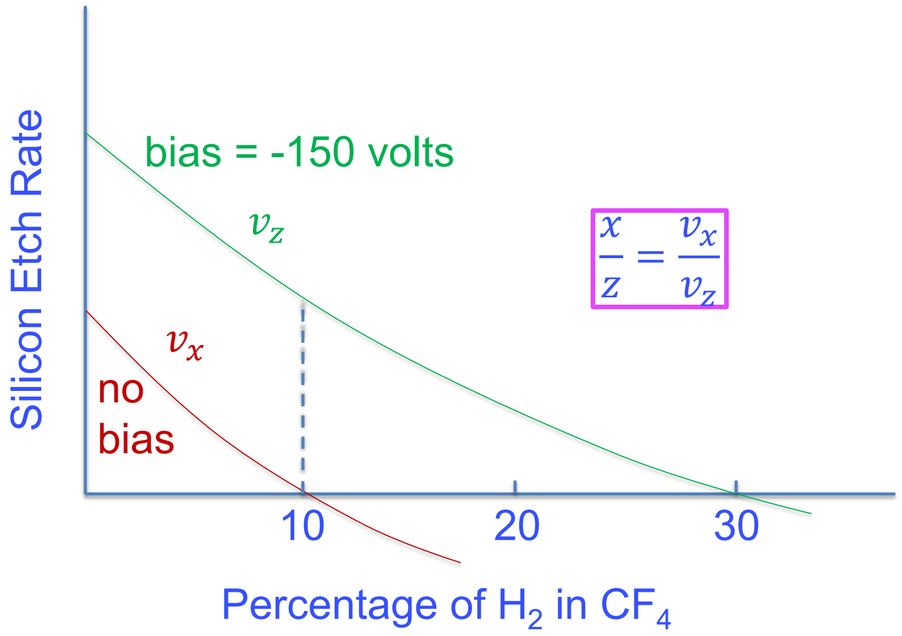
Increasing the anisotropy by sidewall protection

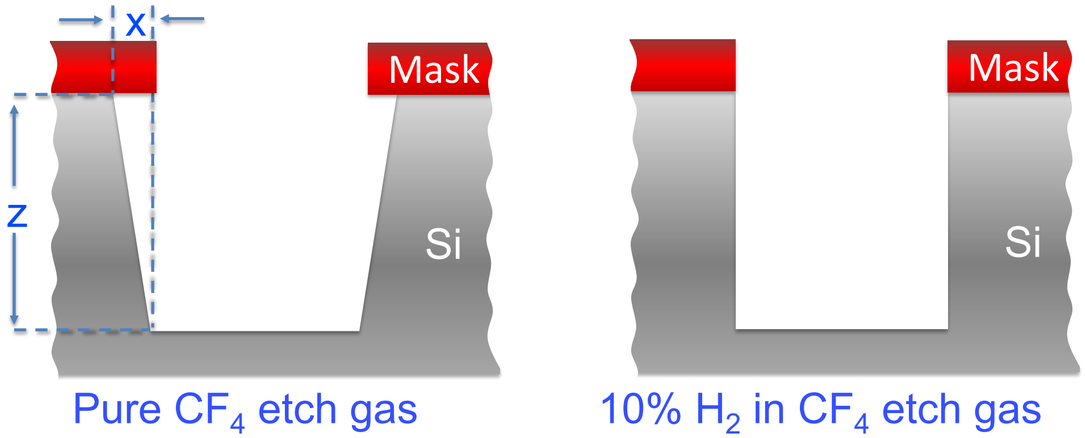


Boundary between etching and polymerization in fluorocarbon plasma as a function of F/C ratio (feed gas) and of the ion bombardment of the surface

- Example: for a ratio of F/C=2.5 with 200 eV ions, the horizontal bottom surface of the feature will be etched, but deposition will be dominant on the sidewall, where ion bombardment is lacking
- This results in the absence of underetching and an anisotropic etching profile
- Adding O_2 increases the F/C ratio
- Adding H_2 decreases the F/C ratio

Effect of adding H_2 to CF_4 gas





- Adding H_2 to the CF_4 gas decreases etching rate, because fluorine reacts with H so that carbon compounds polymerise
- For 10% of H_2, this results in the absence of underetching and an anisotropic etching profile

Simple rules for choosing dry etchants

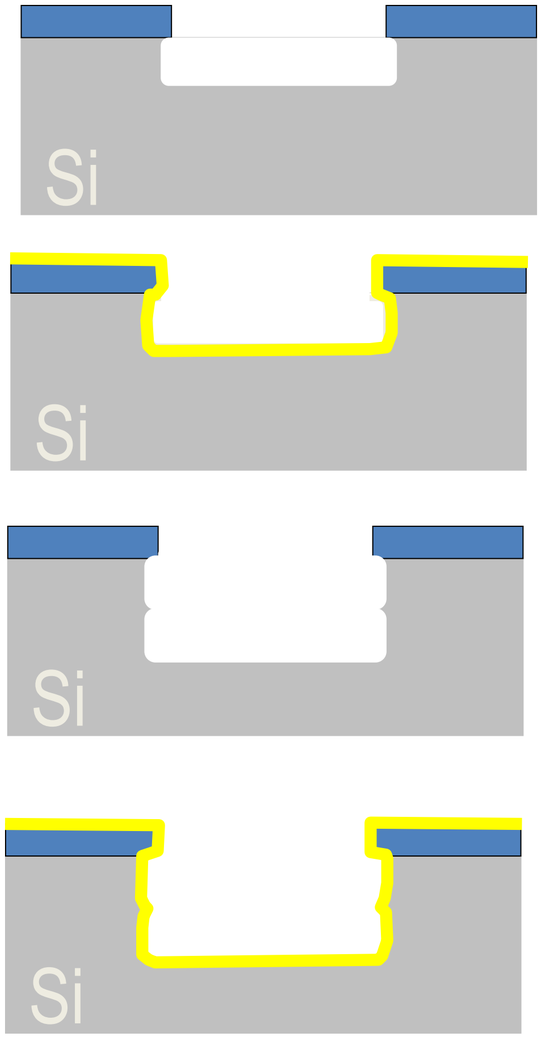
1. Fluorine-to-carbon (F/C) ratio

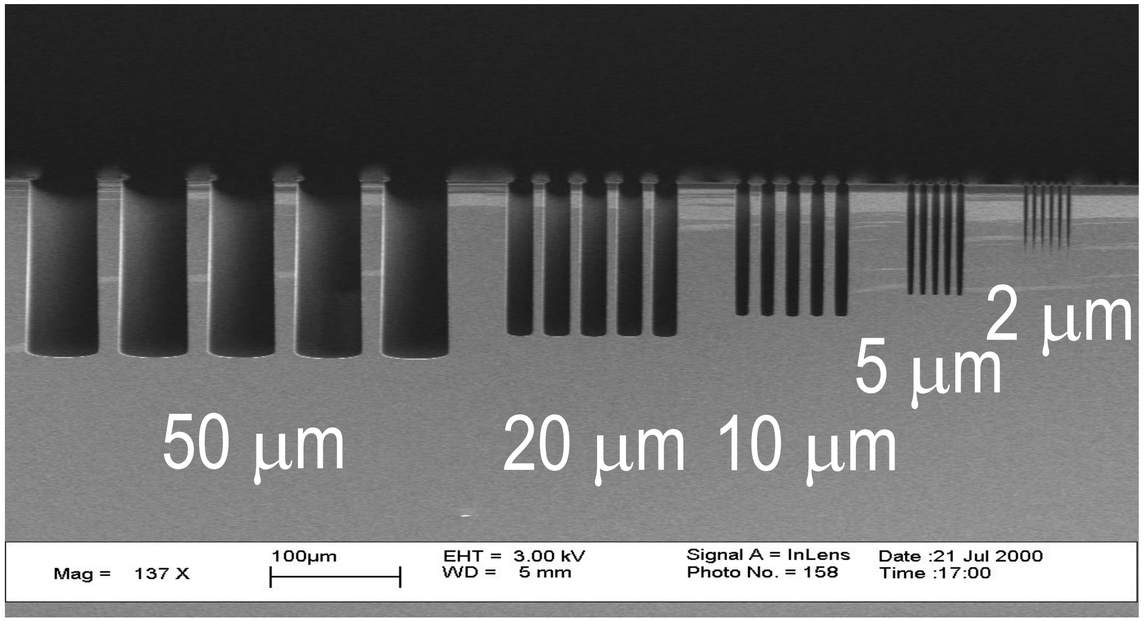
- Etching stems from fluorine, polymerisation from hydrocarbons
- Adding H_2 causes HF to form and the F/C ratio drops, leading to more polymerisation and less etching
- Adding O_2 leads to CO and CO_2 reaction product formation, increasing F/C ratio, leading to more aggressive etching

2. Selective versus unselective dry etching

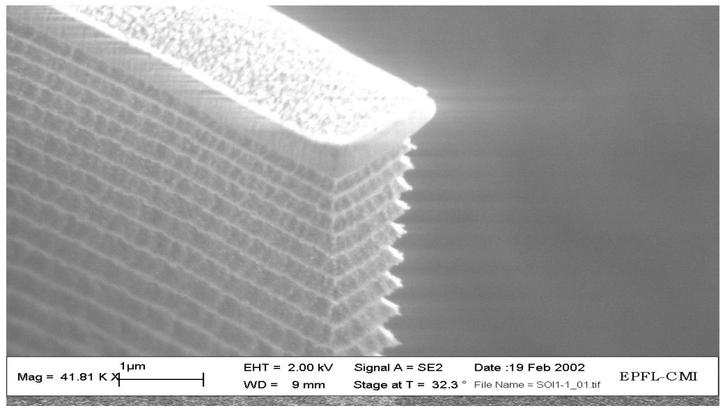
- Polymerisation point of gas determines selectivity
- Decreased temperature, high H_2 concentration, low power, high pressure, and high monomer concentration increase polymerisation, hence selectivity

Deep dry etching of Si: pulsed or Bosch process

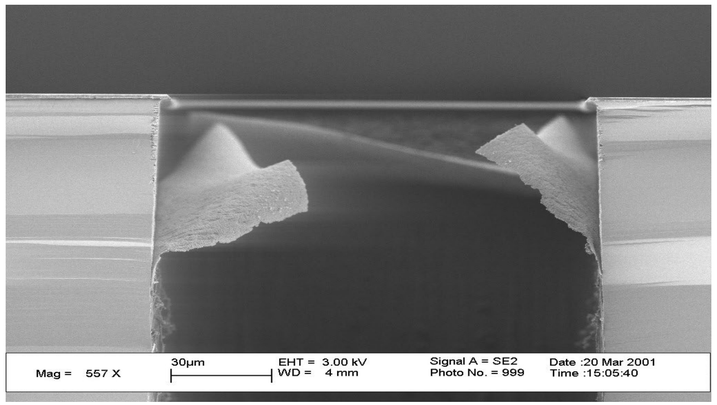




Loading effect

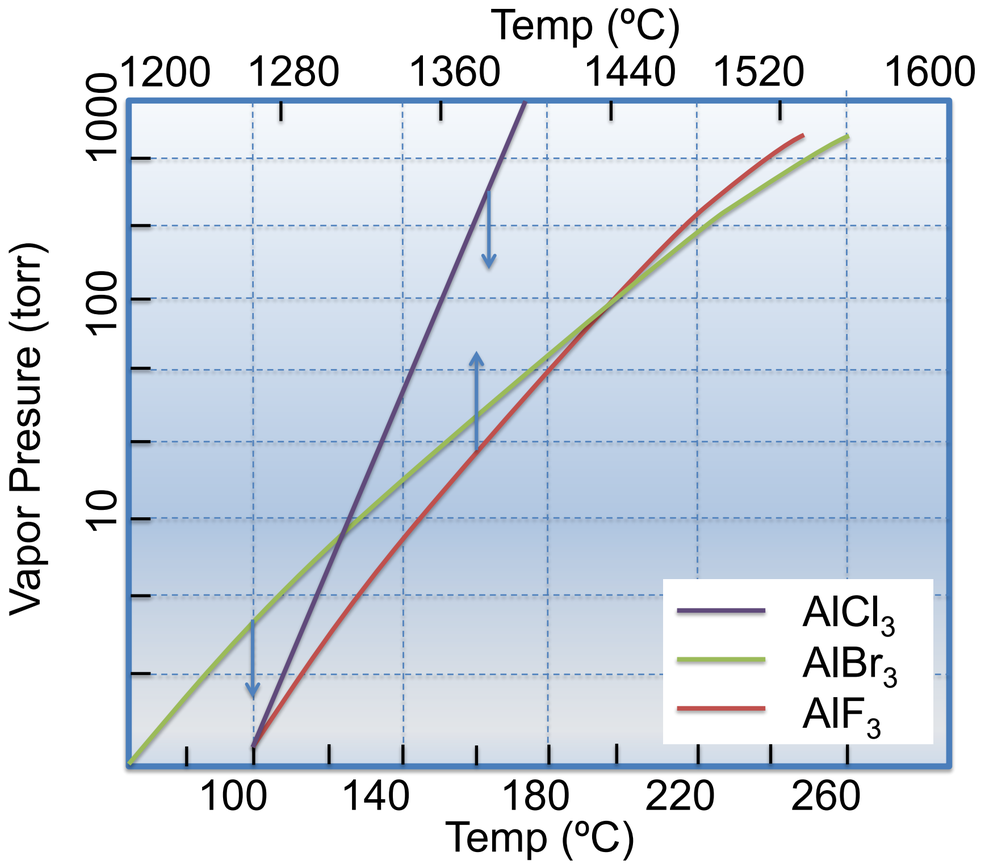


Scalloping effect



Polymer deposition

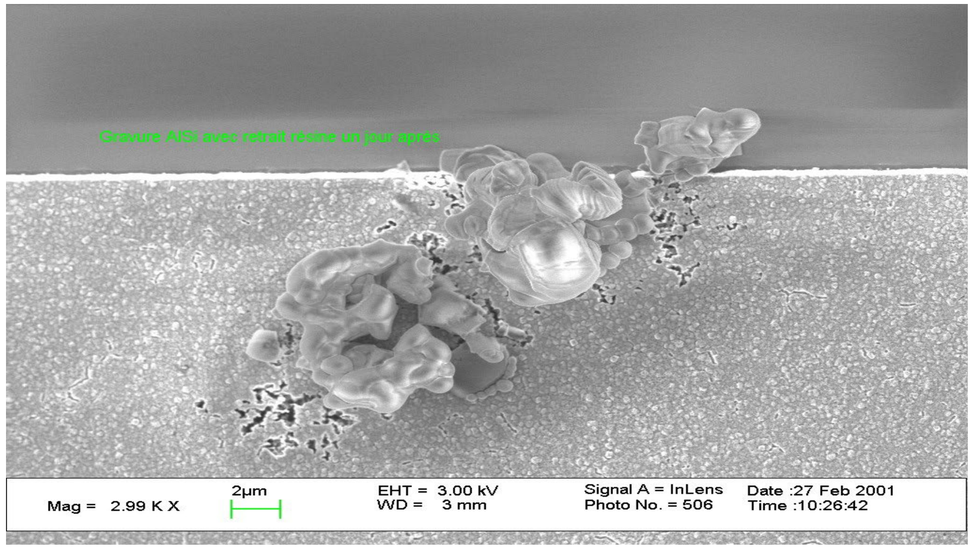
Etching of Al and Al alloys



Vapor pressure of AlF_3, $AlCl_3$ and $AlBr_3$ as function of T
(after D.R. Stull, Ind. Engr. Chem., 39, 517, (1947))

- Al and Al alloys are used for interconnection lines in IC fabrication
- Fluorine chemistry (used for Si and SiO_2) doesn't work for Al etch, because the etch product AlF_3 has a very low vapor pressure
- Chlorine chemistry is used instead
  - Etch product is $AlCl_3$
  - Used gases: BCl_3, CCl_4, $SiCl_4$ and Cl_2

Post-etch corrosion of Al



Anisotropic etching of 1.5 µm AlSi(1%) on SiO_2, after waiting 24 hours before stripping of photoresist

- Chlorine-containing residues remaining on the film sidewalls
- Moisture absorption leads to HCl formation and formation of the Al corrosion product $AlCl_3$
- More severe problem in case of Al-Cu alloys etching, due to the galvanic couple between Cu and Al
- Can be avoided by rinsing wafer in DI water, plasma ashing (O_2) to remove PR and Cl atoms, restoring the passivating Al_2O_3 layer, or exposing Al to a fluorine plasma, replacing Cl atoms by F atoms